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Applications of Mobile Computing for Fish Species at Risk Management

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Applications of Mobile Computing for Fish Species at Risk Management

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Abstract. This paper describes the on-going development of a web-based and Mobile Environmental Management System (MEMS) prototype specifically tailored to perform context-aware queries and updating of spatial datasets. Spatially enabled computing can provide situation aware assistance to both web-based and mobile users by presenting the right information at the right time, place, and situation using context-associated knowledge. Context-associated knowledge is assembled by combining knowledge gained about information accessed in the past with the activities planned by the user, together with other situation dependencies (e.g. location) of these activities. The MEMS datasets are provided by the Canadian Department of Fisheries and Oceans (DFO) and the prototype is customised to the specific needs of the Great Lakes Laboratory for Fisheries and Aquatic Sciences (GLLFAS) Fish Habitat Section's requirements for fish species at risk assessment. Currently, researchers, habitat biologists and enforcement officers have access to the fisheries database, containing layers of biological information (e.g. spawning sites, weed beds, substrate type, etc.) solely from the office. Delivering these data overlaid on base maps of the Great Lakes region to a spatially enabled hand held device and linking it to each task currently being investigated will allow for mobile GLLFAS biologists and enforcement officers in the field to make informed decisions immediately.

Keywords: Spatially Enabled Mobile Computing, Web-Based GIS, Fish Species at Risk.

1 Introduction

The research proposed concerns DFO priorities related specifically to Fish Habitat Management and incorporates and extends ongoing investigations into fish species at risk. The Fish Habitat Management Group of the DFO administers the fish habitat provisions of the Fisheries Act, in particular, those that are aimed at preventing the harmful alteration, disruption or destruction of fish habitat. This is done to conserve, restore and develop the productive capacity of habitats for recreational, commercial and subsistence fisheries both in the freshwater and marine environments [Minns 1997, 2001]. If work is to be done in, or around, the water (e.g. putting in a dock), a proposal must be filed with this group and approved by a habitat biologist. Habitat biologists make their decision based on any number of geographic and biological characteristics of the site where the work is to be carried out. Currently, habitat biologists and enforcement officers have access to the national fisheries database, containing layers of biological information (e.g. spawning sites, weed beds, substrate type, etc.) solely from the office.

The fundamental research challenge of this project is to deliver these data overlaid on base maps of the Great Lakes region to a spatially enabled hand held device contextually linked to each case currently being investigated. The high-level functionality that GLLFAS biologists envisage for the MEMS prototype includes access to geo-referenced maps and imagery, overlay their positions on the maps, manipulate (e.g. input/edit/query) attribute data in the field while wirelessly connected (where possible) to the office database. Additional functionality to the base MEMS requirements for the developed prototypes are user annotation capabilities directly on digital images taken in the field, speech to text recognition for filling out field data sheets, scientific name/common name linking for fish species and other relevant field observations (e.g. vegetation, insect life, etc.), and laser range finding input.

The current "fish species at risk" workflow, whereby scientists enter textual/pictorial information on paper field data sheets is inefficient, has potential for inaccuracies during both initial recording and subsequent data entry phases, and does not facilitate knowledge sharing between staff. Also, different types of information may be stored in different locations and valuable time can often be lost trying to correlate data in order to make decisions. The proposed MEMS system has the following advantages over current practice:

- Facilitates knowledge sharing and data analysis/synthesis.
- Supports effective communication between different staff at different physical locations (e.g. scientists in the lab and colleagues in the field).
- Allows important multimedia data and associated annotations to be combined with text-based records.
- Saves time and money by reducing paperwork and allows staff to input and access information anywhere at any time without having to return to dedicated access points.
- Reduces error by reducing latency between collection and data entry, as well as paperwork.

The remainder of this paper is organised as follows: Section 2 presents the background to MEMS. Section 3 describes the proposed system architecture. Section 4 describes the process of migrating the current data format used by the GLLFAS Fish Habitat Section to Oracle Spatial. Finally, Section 5 provides a summary on the overall contribution of the MEMS prototype/product.

2 Background

To date, users wishing to utilize commercial geo-spatial applications (e.g. Arcview/ArcInfo and ArcIMS; MapInfo and MapInfo MapXtreme, Intergraph GeoMedia WebMap, etc.) in connection with their standard databases are required to use proprietary application-specific software. Integrating existing databases with GIS packages is non-trivial especially if the end users are not GIS experts. More recently, some database vendors have extended their products by providing embedded spatial functionality. For example, Oracle Corporation now provides *Oracle Spatial* that allows for integrated management of spatial and non-spatial data within the same database. [Sharma 2001] This approach overcomes the limitation of traditional GIS where spatial and non-spatial aspects of data are handled by separate database engines. An innovative aspect of the MEMS project relates to its context-aware capability. Context-associated knowledge is assembled by using knowledge gained about information accessed in the past and the activities planned by the user and the situation dependencies (e.g. location) of these activities [Carswell et al. 2004]. Together, these technologies provide exciting new opportunities to dramatically improve decision-making and problem solving based on geo-spatial information.

In recent years, there has been an increasing interest in integrating spatial data with non-spatial data to add a spatial dimension to data collected for many purposes [Shekhar et al. 1999, Rigaux et al. 2002]. Current work for performing context-aware queries applied to a cultural heritage spatial database is under way at the Dublin Institute of Technology (DIT) [Gardiner & Carswell 2003]. Here, a novel solution to querying hyperlinked multimedia cultural heritage datasets based on the user's context has been implemented for both PDA and web-based HCI. In the CHI system (Cultural Heritage Interfaces), the user's location within a VRML model is used to query and deliver cultural heritage content related to their specific geographic location in Dublin. In this system a web page or a simulated mobile device is used to display the data. HHD simulation enables developers to build, and essentially deploy, the spatial application from within the lab which reduces the cost of application development. For example, choosing to simulate the mobile device allows for the accuracy and capabilities of the PDA to be emulated and tested to any degree. For example, emulated location sensing devices can be more accurate than current GPS technology allows. This will allow our application designers to use proposed or not yet ready sensors (e.g. integrated digital compasses, tilt sensors, cameras, altimeters, etc.) in the design of context-aware applications.

An extension to the CHI project relevant to MEMS is to deploy the spatial application on a PDA in the field. As the user progresses through space, the location of the device is determined using a GPS receiver and these data are transmitted using GPRS to the Server. This position is then used as part of a spatial query processed by the database. The results of this query is subsequently transmitted and displayed in real-time on the users PDA. This overall approach has proven effective in many domains for updating and delivering critical task-relevant information [Bertolotto et al. 2004, Carswell et al. 2003, Carswell et al. 2004].

The development of the MEMS system consists of two separate stages. Stage 1 includes the development of an initial prototype that is predominantly web-based with simulated mobile aspects. The main objective of this prototype is to demonstrate a workable system to GLLFAS biologists with an evaluation carried out to determine its capabilities, potential, and recommend enhancements. Stage 2 of the development considers feedback generated from the Stage 1 evaluation. This stage will develop a second, but fully field-operational, prototype employing spatially enabled PDAs and tablet PCs.

3 System Architecture

The MEMS prototypes rely on a typical three-tier architecture for enterprise information systems, composed of the client layer, application server layer, and the database layer. This architecture focuses the load on the application server layer of the system, allowing for a thin client necessary in a mobile context. All communications between the client layer and the database are conducted through the application server layer. With this type of architecture, the processing load is balanced, as each tier of the system resides on a separate computer (Figure 1). Also, this architecture allows for the development of individual components of the system separately, thus maintaining component independence. In this way, different parts of the system can be developed at different stages, some more than others, without affecting the entire system each time a change needs to be made. For example, this architecture has proven ideal for developing Extensible Markup Language (XML) based applications because all XML/XSLT processing is carried out on the middle tier of the system, without affecting client and/or database tier manipulation/development [Carswell et al. 2004].

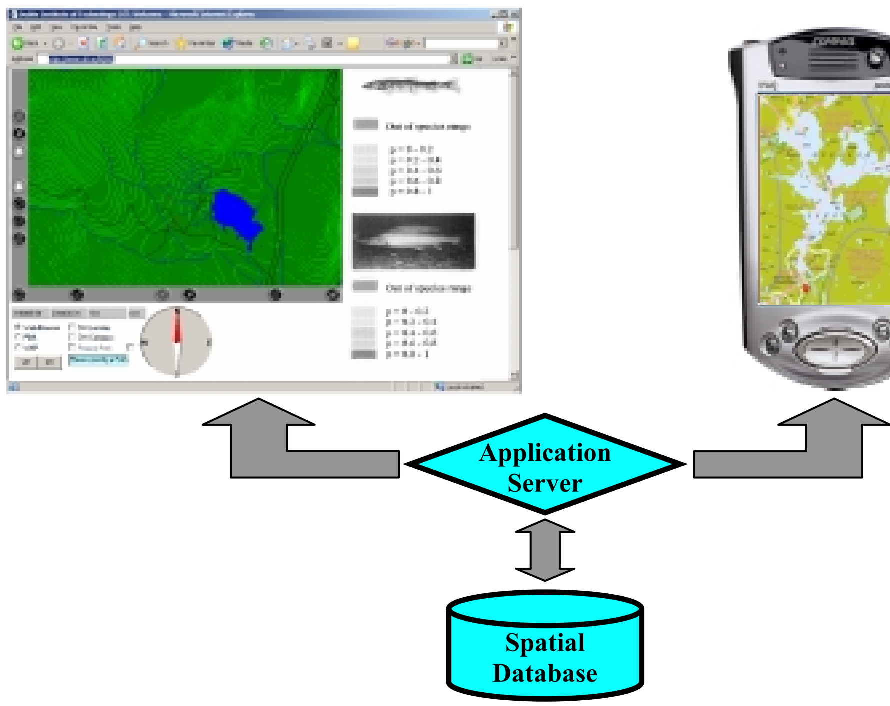

Figure 1: Three-tier Architecture

3.1 Client Layer

The client layer of the system consists of a web-based, data-editing tool to provide biologists with capabilities to edit and annotate the data in the system. Initially, as the user navigates within a 3D model, the position and orientation is simulated, and used to load data into the database and query for previously loaded data. For use in the field, the users also have a Personal Digital Assistant (PDA) equipped with a Global Positioning System (GPS) receiver for determining the position of the device and General Packet Radio Service (GPRS) capabilities for requesting and transmitting data to, and from, the Application Server. Delivery of data to the client is a core research aspect of the project. For desktop web-based access, the content delivery is not affected by bandwidth restrictions. However, mobile aspects of the system require a streamlined design because current speed and bandwidth capabilities of these devices are not comparable to desktop PCs. Therefore, content delivered to these devices needs to be scaled down to deliver it efficiently. This can be achieved by using a device-specific content adaptation approach.

3.2 Application Server Layer

The application server layer of MEMS is responsible for formulating all spatial queries, inserts and updates to the system and acts as the main hub between the client and database. This layer contains several Enterprise Java Beans (EJBs) illustrated in Figure 2 and described in the following.

The *MEMS EJB* is responsible for all communication with the client - an object of this type is instantiated for each user session and monitors changes in the user's context. For example, if the position of the user's location in space changes, new coordinate information is passed to this EJB. Other relevant context data are also passed at this time including the type of mobile device currently in use. SQL statements are needed to determine and retrieve the information to be displayed on the client side. For example, when the user's context is received from the *MEMS EJB*, a query is constructed and sent to the Oracle database engine for execution. The query results are returned to the *MEMS EJB*, which organizes the results into device specific format. If the same query applies again (i.e. no change in user context), the *MEMS EJB* reuses the previous result set. Previously executed SQL commands are cached by the EJB thereby eliminating the need to re-interpret queries. A typical cycle through the MEMS system is illustrated in Figure 2.

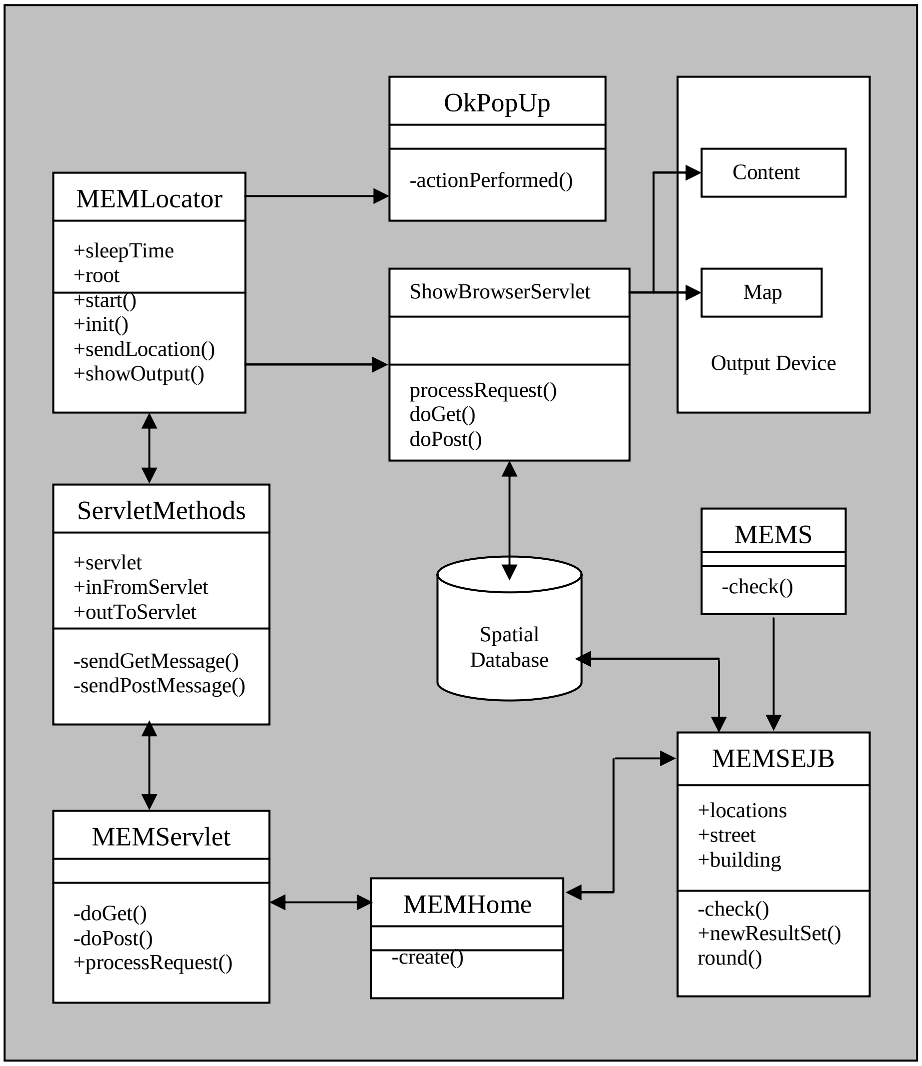

Figure 2: Application Server Layer EJBs and Communications

All requests made by the application layer are made by the *sendLocation* method within the *MEMLocator* class, which is called consecutively at an iteration cycle that corresponds to the *sleepTime* variable specified within the system. The method retrieves all the information required from the client side applet and sends it to the *MEMServlet* object via the *ServletMethods* object. The *ServletMethods* class is an abstract class for accessing Servlets and is independent of the Servlet and its location. Once the *ServletMethods* class has been initialised, the information obtained from the applet is passed to the application server *MEMServlet* class. This class is the client component of the *MEMS Session EJB* that performs all the server-side processing. An instance of the *CSTestBean* is created through the *MEMHome* interface and a remote connection is made to the *MEMBean* using the MEMS interface.

This remote connection enables access to the methods contained within the bean. The Servlet is never connected directly to the bean, rather all connections are made via the two interfaces.

After the coordinate information is passed to the bean, a connection is made to the database and the query results extracted and sent back to the *MEMLocator* applet along the same path (Note: Servlet and EJB technologies all exchange information by opening bi-directional connections). The returned data, which consists of record IDs, is then passed to the *ShowBrowserServlet*, to extract the relevant data and format it for a selection of platforms, including a PDA and a standard Web Browser. XML is used in conjunction with XSLT (extensible stylesheet language transformations) to convert XML data into the various required formats e.g. HTML, WML, etc. The advantage of using XSLT for such a scenario is that the underlying XML data structure remains the same, and by applying XSL stylesheets the data is formatted on the fly to whatever format is desired by using an XSLT processor. Figure 3 illustrates the process of transforming XML into device specific format.

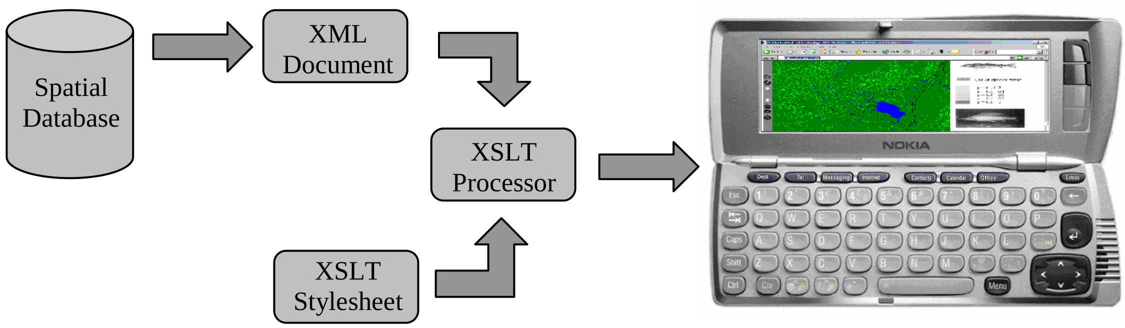

Figure 3: Device Adaptation Workflow using XML/XSLT

3.3 Database Layer

The spatial database layer of MEMS is responsible for processing all queries, both spatial and transactional, in the system. We are using Oracle Spatial that includes SDO, a spatial extension to SQL. This database introduces new spatial data capabilities, e.g. geocoding and topological queries. This tier stores all spatial and non-spatial data including raster (map) data and any metadata as well as the topological properties of these data. Spatial data types can be inserted, stored, manipulated and queried in the database as they are represented in physical space. Also, Oracle Spatial is integrated into the extensible Object Relational Database Management System (ORDBMS), which allows access to the full functionality and security of the underlying DBMS [Sharma 2001].

4 GLLFAS Data Migration

Currently, the spatial data used by MEMS reside in a GLLFAS Microsoft Access database - a purely relational database without any spatial capabilities. This limitation presents problems when analysing/manipulating data based on spatial properties. To exploit the full potential of these data, they are imported to a spatial database using a migration workbench utility that transforms numerical fields (with no spatial properties) into Geometry columns in the Oracle database [Shekhar et al. 2003].

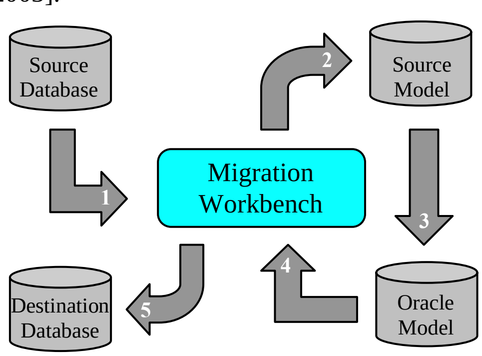

Figure 4: Database Migration Workbench

The data migration process begins by exporting the data from the Access database into an XML file called the *Source Model*. The source model is used to create the *Oracle Model*, which is checked for errors that may have appeared while exporting the data. If the integrity of the database is intact, the migration workbench creates a database in Oracle identical to the source database (Figure 4).

4.1 GLLFAS Data Dictionary

GLLFAS utilizes a hardcopy data sheet to record sampling sessions while in the field with the collected data subsequently entered into the Fish Habitat Management database when back at the office - usually during the winter months. MEMS replaces this two-step approach by allowing field biologists to enter data directly in the field, thus enabling users both on-site and in the office with query/analysis/decision making capabilities immediately and all year round. During the migration of the GLLFAS database into Oracle, most of the datatypes remain the same except for the *start location* and *stop location*. These two fields are now mapped to spatial datatype fields to enable exploitation of the spatial properties inherent with the lat/long values. Table 1 describes all database fields.

Table 1: GLLFAS Data Dictionary

Field	Description	Format
Project Name:	This is the project name used for the duration of field studies and is decided by the SAR Field Coordinator.	Text
Project Number:	This is the project code and consists of a four-letter acronym that describes the project name and two numbers to signify the appropriate year of sampling.	Text
Date:	This is the date and is of the following format Month/Day/Year	Text
Water body Name:	This is the water body name associated with the site.	Text
Arrival Time:	This is the time of arrival at the site prior to sampling and is recorded in military format (e.g. 1300 hrs).	Number
Departure Time:	This is the time of departure form the site on completion of the sampling and is recorded in military format.	Number
Start Time:	This is the time that sampling begins and is recorded in military format.	Number
Stop Time:	This is the time the sampling is completed and is recorded in military format.	Number
Start Location:	This is the Lat/Long location at which the sampling begins and the GPS units are set at NAD 83 in dec. deg. (dd.dddddd°).	Float
Stop Location:	This is the Lat/Long location at which the sampling ends and the GPS units are set at NAD 83 and are in dec. deg. (dd.dddddd°).	Float
Sampling Method		
Gear Type:	This is the gear type used while sampling.	Text
Effort:	This is the sampling effort expended while sampling.	Text
Site Characteristics		
Air Temperature:	This is the air temperature prior to sampling (units = °C).	Number
Water Temperature:	This is the water temperature prior to sampling (units = °C).	Number
Conductivity:	This is the water conductivity prior to sampling (units = μS/cm).	Number
Dissolved Oxygen DO	This is the level of dissolved oxygen and is recorded in ppm.	Number
pH:	This is the pH level.	Number
Secchi Disc:	This value is recorded form the disc (units = 0.00 metres)	Number
Substrate Description		
Type:	This is the type of substrate in the area.	Text
Size:	This is the size of the substrate type components.	Number

Field biologists are also required to sketch a map of the area that the sampling takes place by drawing an outline of the site manually on the data sheet. In MEMS, this process is replaced by utilizing a digital camera to capture an image of the test-site with self annotation and automatic coordinate input functionality available directly on the image. Further imaging capabilities are exploited when recording fish species captured, kept, and released. In this case MEMS enables the biologist to take a picture of the specimen, look up the scientific name of the fish in the name lookup table and upload all information automatically into the database.

5 Summary and Conclusions

The MEMS project is about researching and developing a *Mobile Environmental Management System* prototype/product specifically tailored to perform web-based and mobile context-aware queries and updating of spatial datasets. The project builds on EI (Enterprise Ireland) funded research into context and location-aware computing currently under way at DIT and UCD. MEMS is designed to enable the Fish Habitat Section at GLLFAS to manage fish species at risk using exact positions of field data and tests carried out and uploaded at the position they are obtained. For example, the system allows biologists to take pictures of fish and other related field data and annotate/upload them into a database using a PDA or tablet PC combined with GPS, GPRS and a digital camera. Additional system capabilities not currently available to existing practice include:

- a scientific/common name lookup table plus related imagery to determine proper naming of fish species and other plant/animal life in the field.
- a query facility to the database displays information to the user on a backdrop map centred on the present location.
- a speech to text recognition program facilitates scientists when filling out fields on the data sheet verbally using common or scientific names of fish/plant life.

This innovative research greatly increases the accuracy of field data being recorded, and removes the need for twice entering the same data (i.e. once in the field and again, sometimes months later, in the office) thus increasing productivity and allowing for informed decision making while still in the field.

There are two main approaches in which the MEMS implementation achieves this. The first is to deliver the content to standard browsers such as Internet Explorer and Netscape Navigator. In this case the content is delivered in HTML format over a standard TCP/IP wired network. The content is then parsed and presented to the user in the browser. The second is to deliver the content over a wireless network. However, unlike traditional fixed line networks that typically use HTTP on top of the TCP/IP layer, wireless technology is still in the early stages of becoming a universal standard. There are a multitude of incompatible protocols and technologies all trying to achieve the same end, but in different ways.

In recent times there is much publicity for technologies such as Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Enhanced Data for GSM Evolution (EDGE) and Universal Mobile Telephone Service (UMTS), as it is envisioned that wireless access would soon be more popular than fixed line access. However, the reality is that deploying high-speed wireless networks is taking longer than initially expected. For example, already there are long delays in the deployment of universal 3G networks, and predictions suggest that even by the year 2010, third generation networks will account for less than a quarter of the global market [Horvath 2001]. For now though it seems that technologies such as GPRS and EDGE will be the most utilised. However, 2G systems such as GSM are expected to be operational for many years to come and will continue to be upgraded and enhanced to GPRS and EDGE transmission standards. Eventually some of these newer technologies may be incorporated into MEMS but initially the main technologies we employ are GSM and GPRS.

5.1 The MEMS Initial Technology Prototypes

Two *Initial Technology Prototypes* (one web-based, the other mobile) will be built that allow a user to navigate through a virtual model of Canadian wilderness depicting a typical DFO user’s Fieldspace and display task specific data relevant to his/her location in this space. The virtual model may contain digital charts and other imagery rendered using VRML (Virtual Reality Modeling Language). As the user moves within this 3D world, his location or virtual space coordinates are concurrently transformed into real world geographic coordinates (latitude/longitude). These lat/long coordinates are then passed as parameters for the construction of a query to the spatial database. The query will in effect retrieve all data from the database, within a certain tolerance, of the user’s position in virtual 3D space related to the task at hand, e.g. retrieve all “species at risk” data within +/-100m of these coordinates. The result of the query will be returned to the user’s web-based or hand-held (mobile) device, which will be simulated initially and displayed in parallel with the VRML 3D world on a standard desktop/laptop PC. (Figure 5)

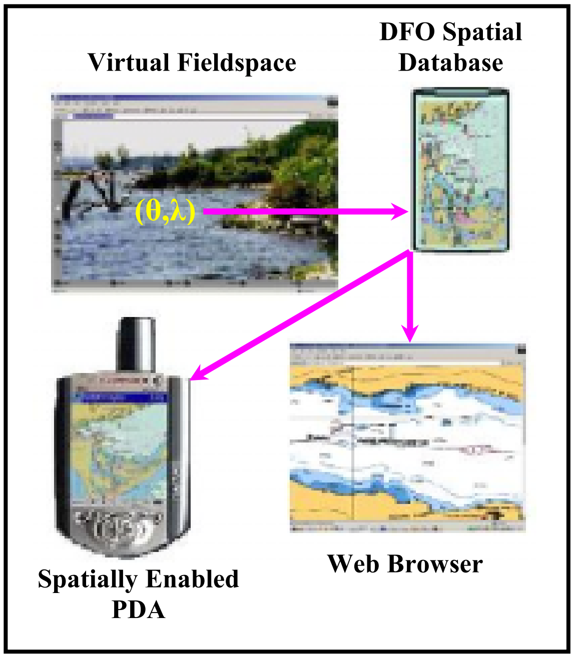

Figure 5: Conceptual Overview of the MEMS Initial Technology Prototypes

The MEMS *Initial Technology Prototypes* allow for the demonstration of the more technical aspects of the project. For example, they will provide a platform to test how the simulated mobile device interacts with and communicates to the user and the database. The main functional requirements of the *Initial Technology Prototypes* include:

<u>*Client Side*</u>

- 3D virtual display of DFO Fieldspace where the user can navigate within using the keyboard/mouse
- A coordinate readout of the user's location in virtual space transmitted to the application server
- Various simulated mobile devices that the user can interact with by clicking on hyperlinks

<u>*Server Side*</u>

- The ability to transform virtual space coordinates into real-world coordinates
- Construct and execute a spatial query based on user context that includes location and mobile device characteristics
- Format the query results according to the mobile device characteristics and relay back to client

<u>*Database Side*</u>

- Organisation of spatial multimedia datasets
- Spatial queries

5.2 The MEMS Revised Technology Products

Two *Revised Technology Products* will build on the capabilities of the initial prototypes by adding the required functionality to allow for actual field testing using real data under real field conditions. This progression to the product phase implies implementation on ruggedized, spatially enabled PDAs and tablet PCs. The main functional requirements of the revised technology products, in addition to those of the initial technology demonstrators, include:

<u>*Client Side:*</u>

- Real hand-held devices replace simulated devices. Real Fieldspace replaces virtual Fieldspace.

<u>*Server Side:*</u>

- Construct and execute a spatial query based on user context that includes, in addition to location and mobile device characteristics, the user's profile – which may include a "theme" or topic of data the user is interested in or a task they are trying to complete.

- *SQL EJB* needs to consider what information has already been sent to the user so as not to re-send redundant data.

Database Side:

- No change.

The *Revised Technology Products* will allow the user to not only interact with the multimedia data available in the MEMS database but be presented with the data in a location-aware and meaningful context. This is achieved by the use of user profiles (e.g. interested in water quality, etc.) and the ability to transmit data adaptively. In other words, the present context of the user will be determined by location, experience, and fieldwork history and the database content will then be compiled on demand, triggered by user events or automatically through location dependent queries.

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Keith Gardiner received a B.Sc. in Applied Computing from Waterford Institute of Technology (Ireland) in 2001 and a Masters Degree in 2004 from the Dublin Institute of Technology (DIT) where his final thesis proposed innovative techniques of directional querying in spatial databases for mobile applications. Currently he is employed as a Senior Researcher at the DIT Digital Media Centre working on all aspects of *MEMS* research and development. His main areas of expertise are the integration of Oracle Spatial with J2EE and Computer Graphics Technologies.

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